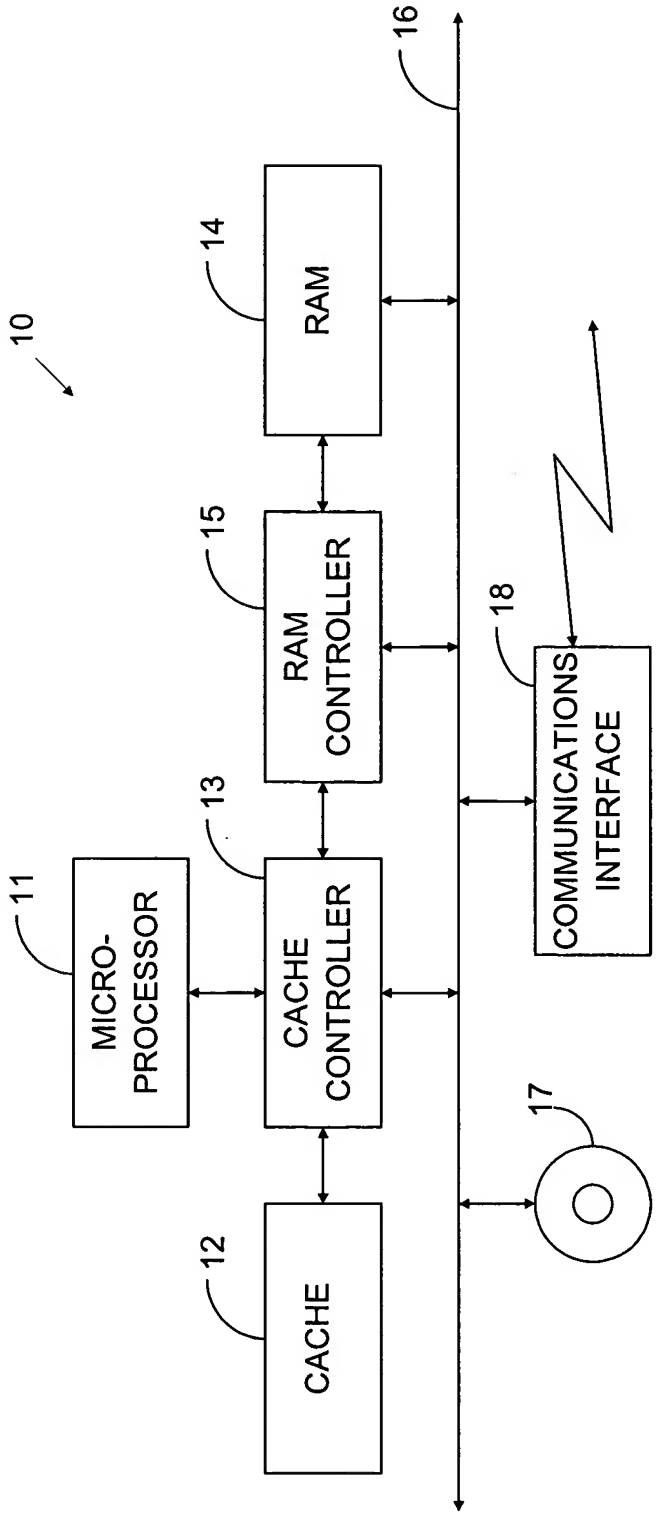
10
11
MICRO-PROCESSOR
12
CACHE
13
CACHE CONTROLLER
14
RAM
15
RAM CONTROLLER
16
17
18
COMMUNICATIONS INTERFACE

FIG. 1

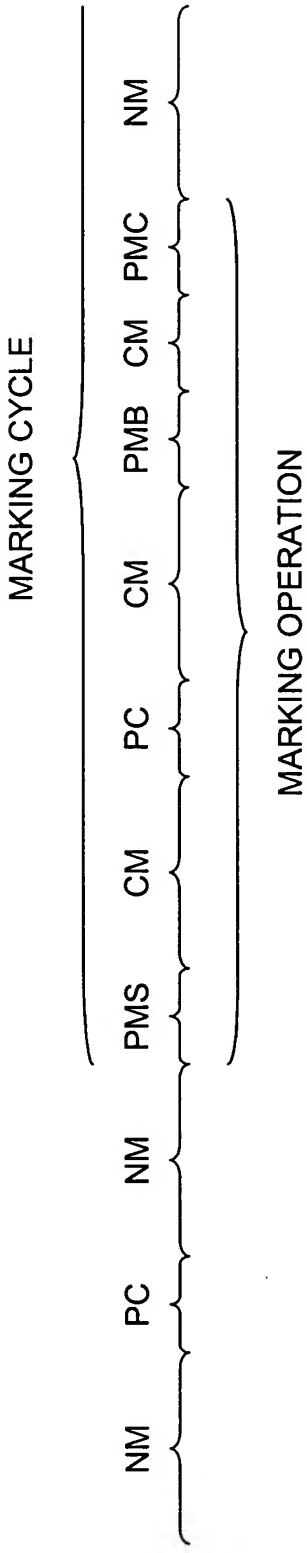
MARKING CYCLE
MARKING OPERATION
NM
PC
NM
PMS
CM
PC
CM
PMB
CM
PMC
NM

FIG. 6

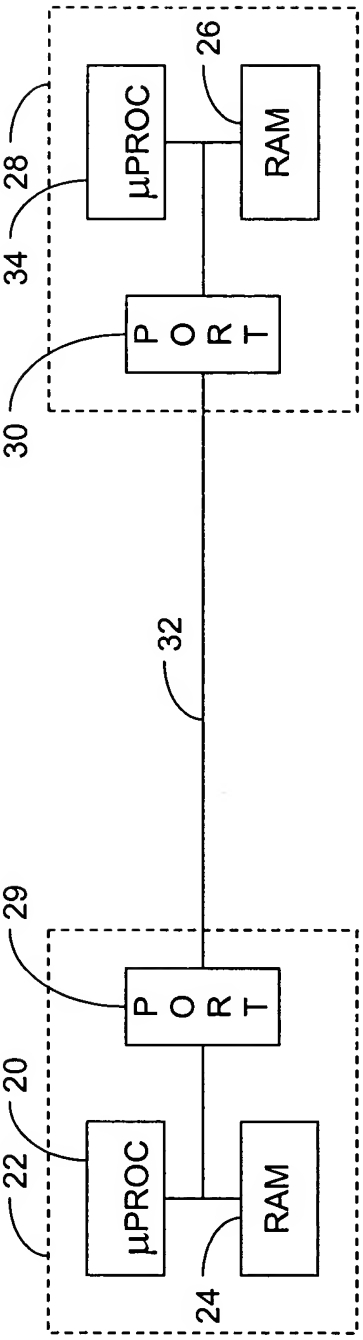
µPROC
RAM
PORT
µPROC
RAM
PORT
26
28
34
30
32
29
20
22
24

FIG. 2

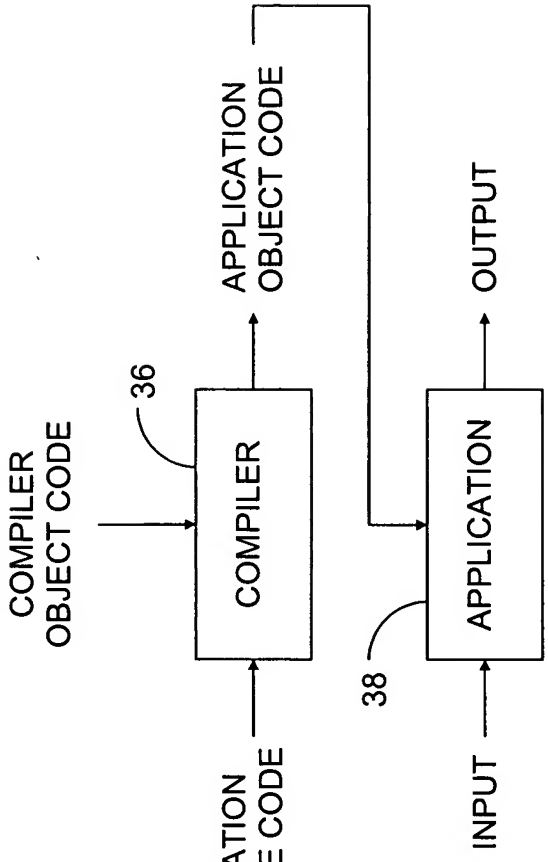
COMPILER OBJECT CODE
COMPILER
APPLICATION OBJECT CODE
APPLICATION SOURCE CODE
APPLICATION
OUTPUT
INPUT
36
38

FIG. 3

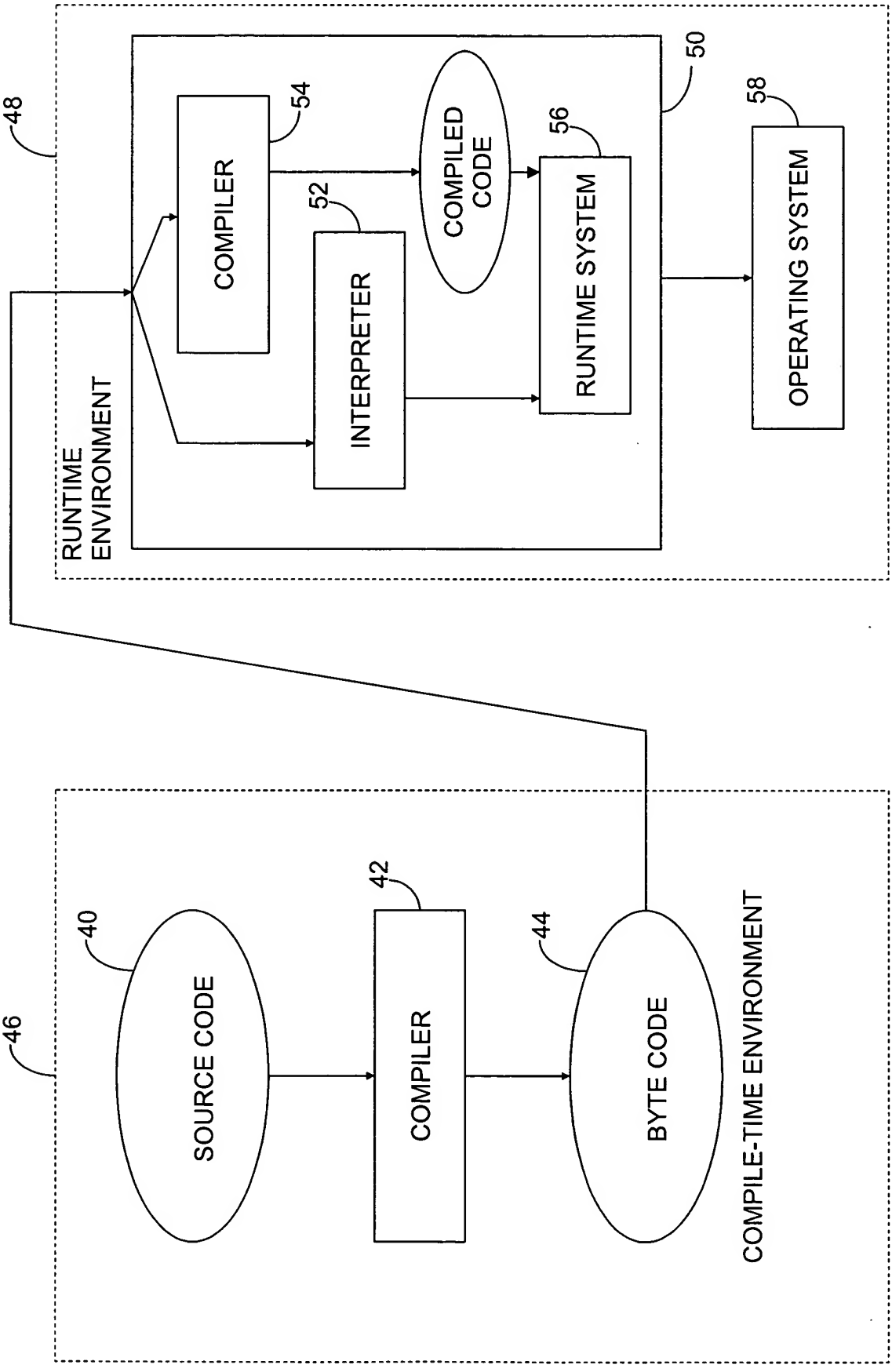
RUNTIME ENVIRONMENT
48
COMPILER
54
INTERPRETER
52
COMPILED CODE
RUNTIME SYSTEM
56
50
OPERATING SYSTEM
58
COMPILE-TIME ENVIRONMENT
46
SOURCE CODE
40
COMPILER
42
BYTE CODE
44

FIG. 4

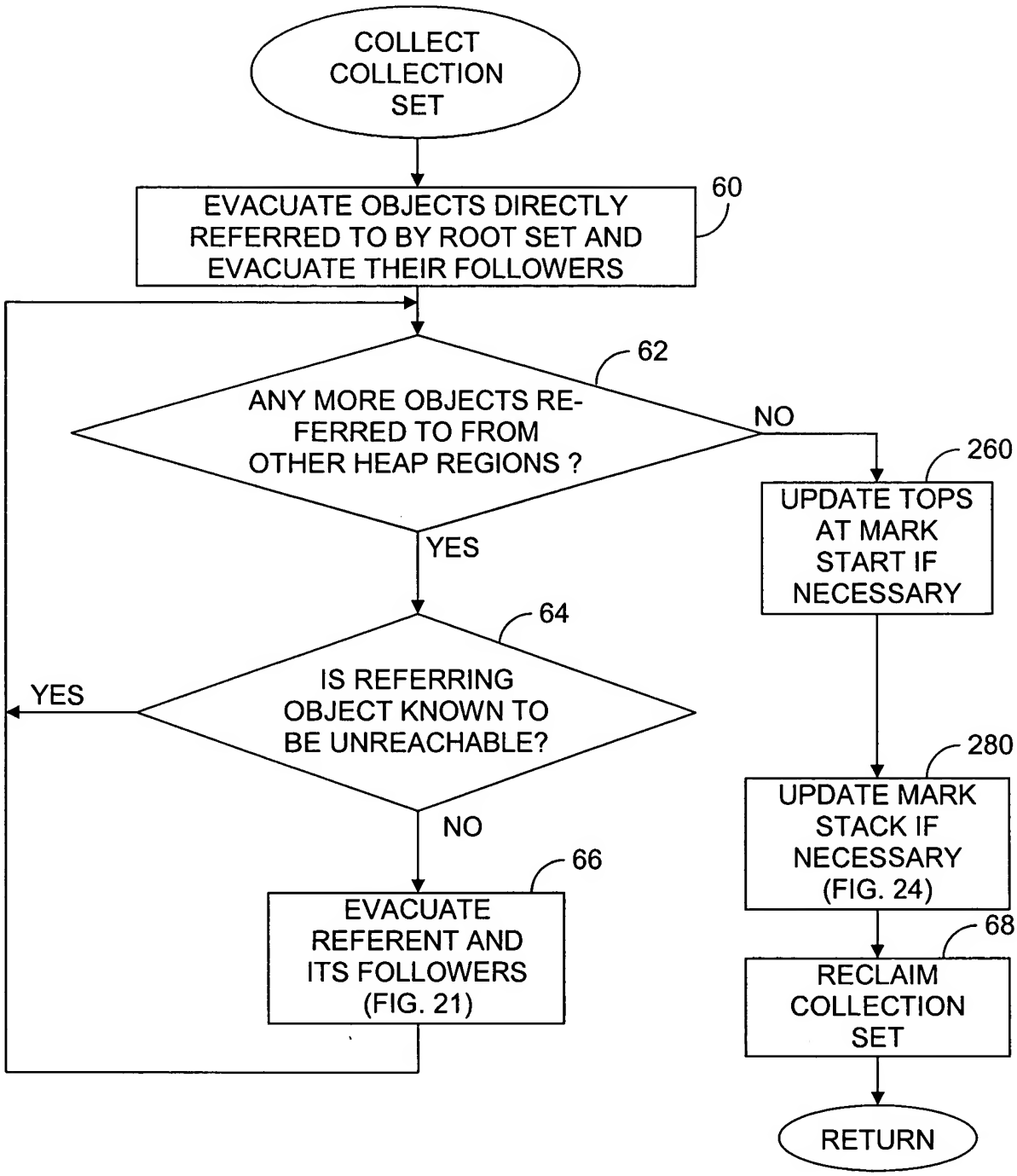
COLLECT COLLECTION SET
EVACUATE OBJECTS DIRECTLY REFERRED TO BY ROOT SET AND EVACUATE THEIR FOLLOWERS
60
ANY MORE OBJECTS REFERRED TO FROM OTHER HEAP REGIONS ?
62
NO
YES
260
UPDATE TOPS AT MARK START IF NECESSARY
IS REFERRING OBJECT KNOWN TO BE UNREACHABLE?
64
YES
NO
280
UPDATE MARK STACK IF NECESSARY (FIG. 24)
66
EVACUATE REFERENT AND ITS FOLLOWERS (FIG. 21)
68
RECLAIM COLLECTION SET
RETURN

FIG. 5

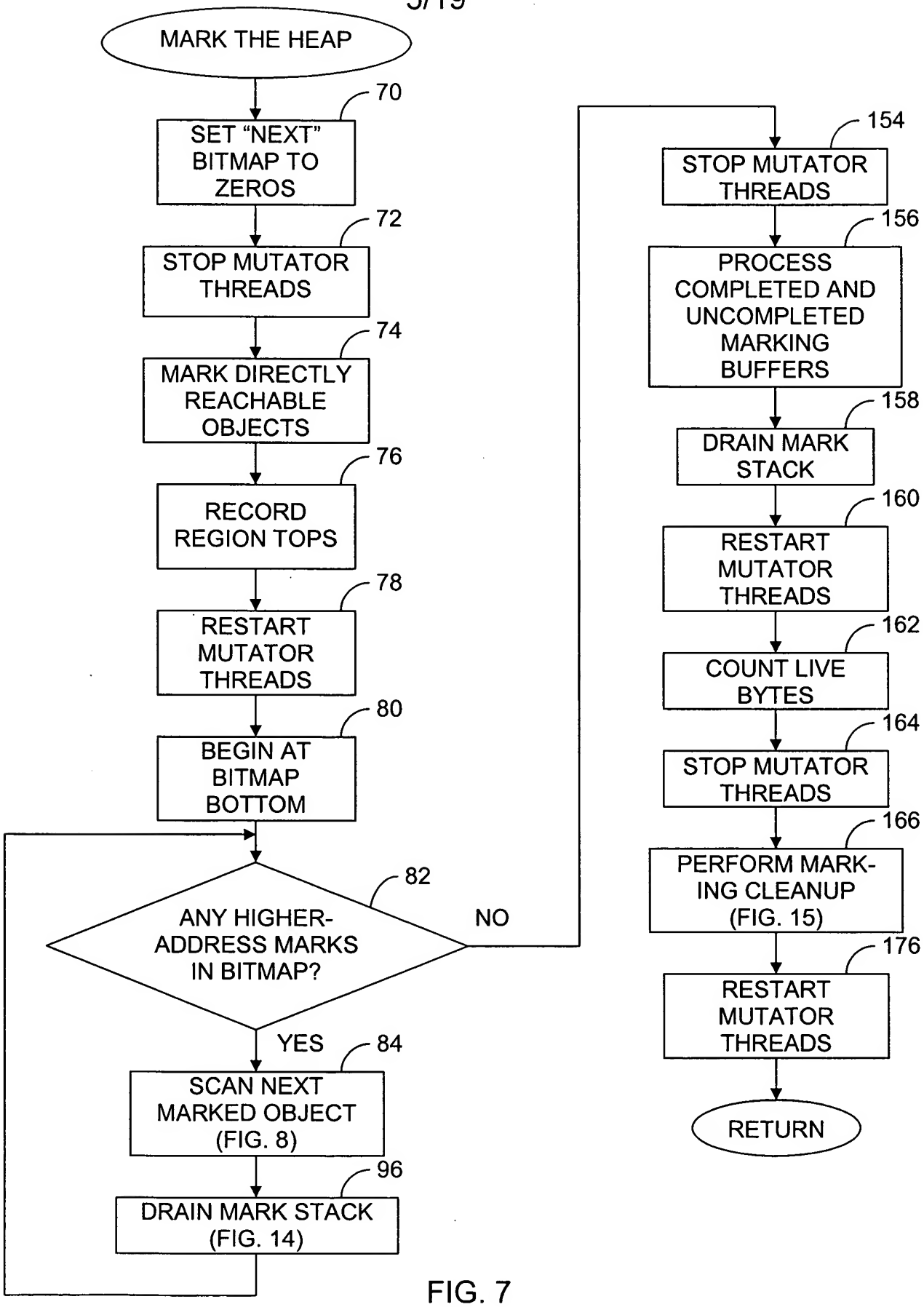
MARK THE HEAP
70
SET "NEXT" BITMAP TO ZEROS
72
STOP MUTATOR THREADS
74
MARK DIRECTLY REACHABLE OBJECTS
76
RECORD REGION TOPS
78
RESTART MUTATOR THREADS
80
BEGIN AT BITMAP BOTTOM
82
ANY HIGHER-ADDRESS MARKS IN BITMAP?
NO
YES
84
SCAN NEXT MARKED OBJECT (FIG. 8)
96
DRAIN MARK STACK (FIG. 14)
154
STOP MUTATOR THREADS
156
PROCESS COMPLETED AND UNCOMPLETED MARKING BUFFERS
158
DRAIN MARK STACK
160
RESTART MUTATOR THREADS
162
COUNT LIVE BYTES
164
STOP MUTATOR THREADS
166
PERFORM MARK-ING CLEANUP (FIG. 15)
176
RESTART MUTATOR THREADS
RETURN

FIG. 7

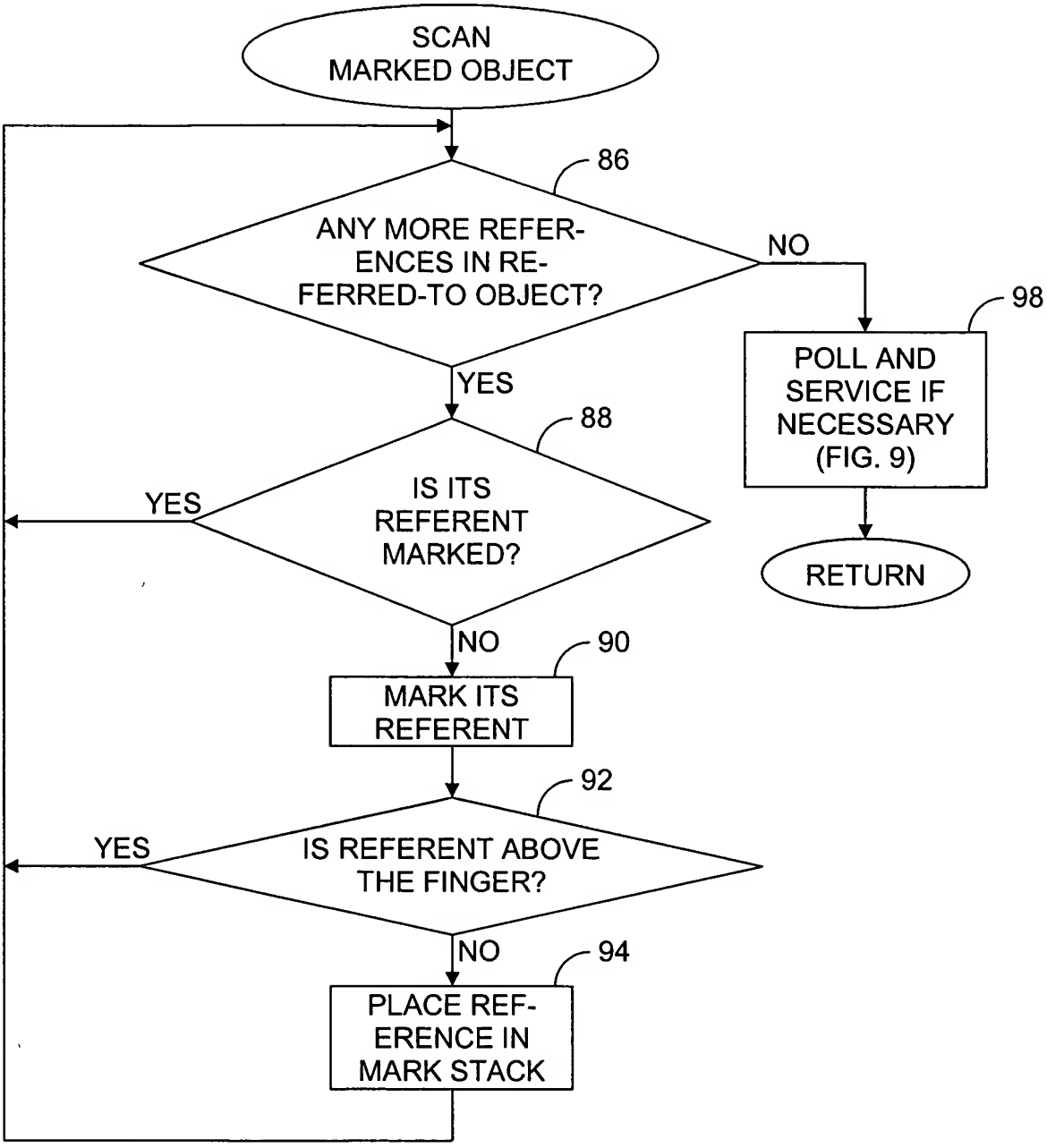
SCAN MARKED OBJECT
86
ANY MORE REFERENCES IN REFERRED-TO OBJECT?
NO
98
POLL AND SERVICE IF NECESSARY (FIG. 9)
RETURN
YES
88
IS ITS REFERENT MARKED?
YES
NO
90
MARK ITS REFERENT
92
IS REFERENT ABOVE THE FINGER?
YES
NO
94
PLACE REFERENCE IN MARK STACK

FIG. 8

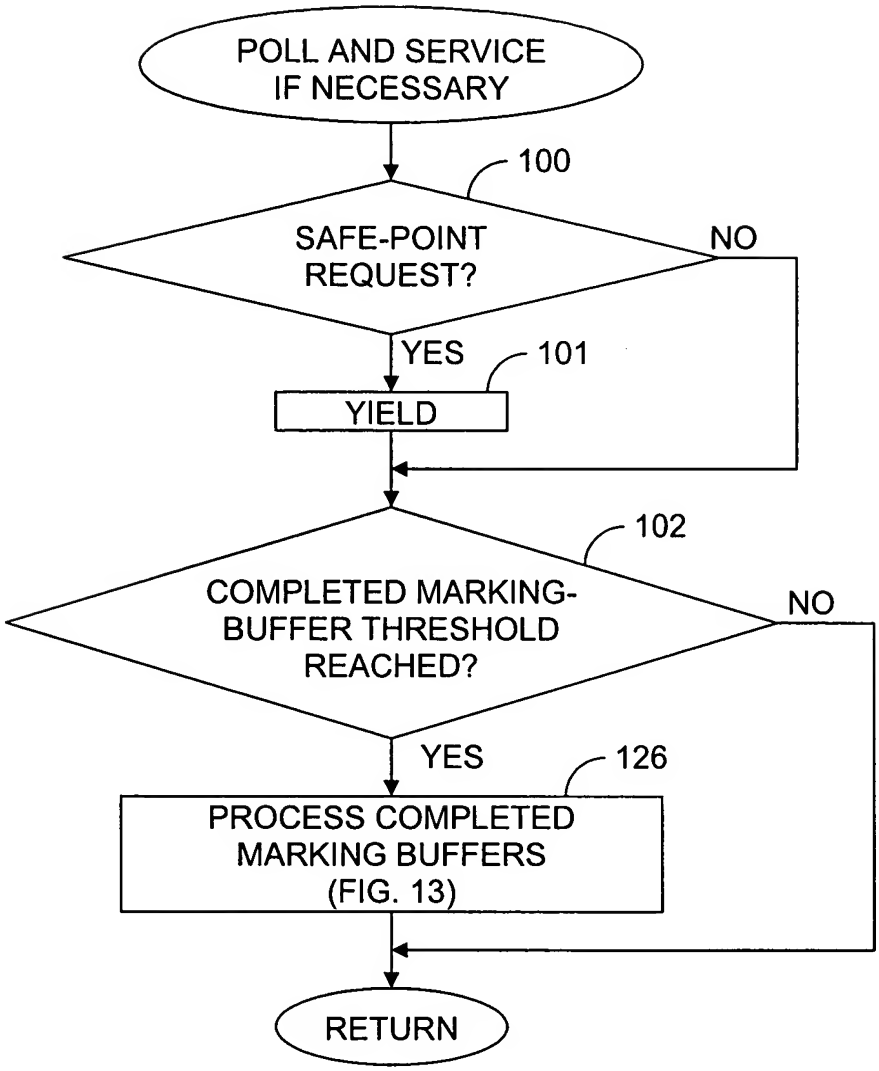
POLL AND SERVICE IF NECESSARY
100
SAFE-POINT REQUEST?
NO
YES
101
YIELD
102
COMPLETED MARKING-BUFFER THRESHOLD REACHED?
NO
YES
126
PROCESS COMPLETED MARKING BUFFERS (FIG. 13)
RETURN

FIG. 9

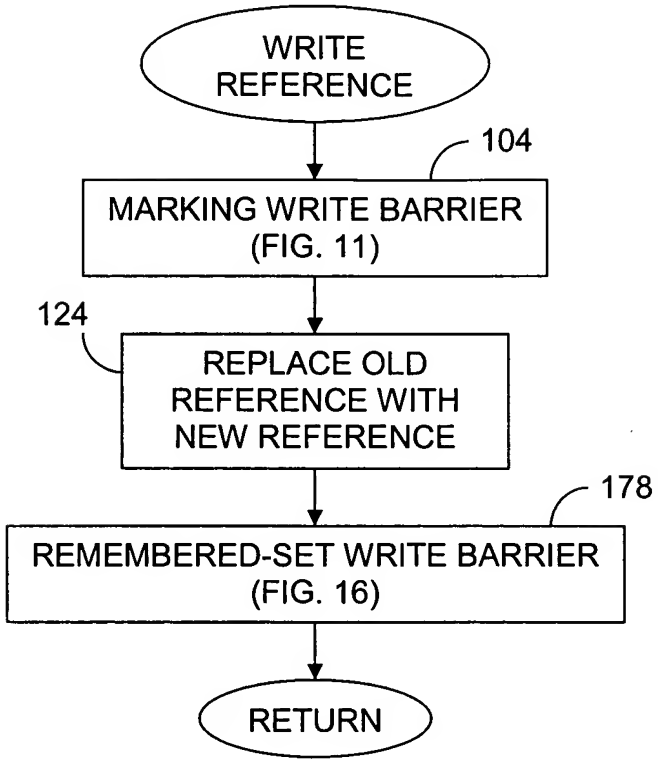
WRITE REFERENCE
104
MARKING WRITE BARRIER (FIG. 11)
124
REPLACE OLD REFERENCE WITH NEW REFERENCE
178
REMEMBERED-SET WRITE BARRIER (FIG. 16)
RETURN

FIG. 10

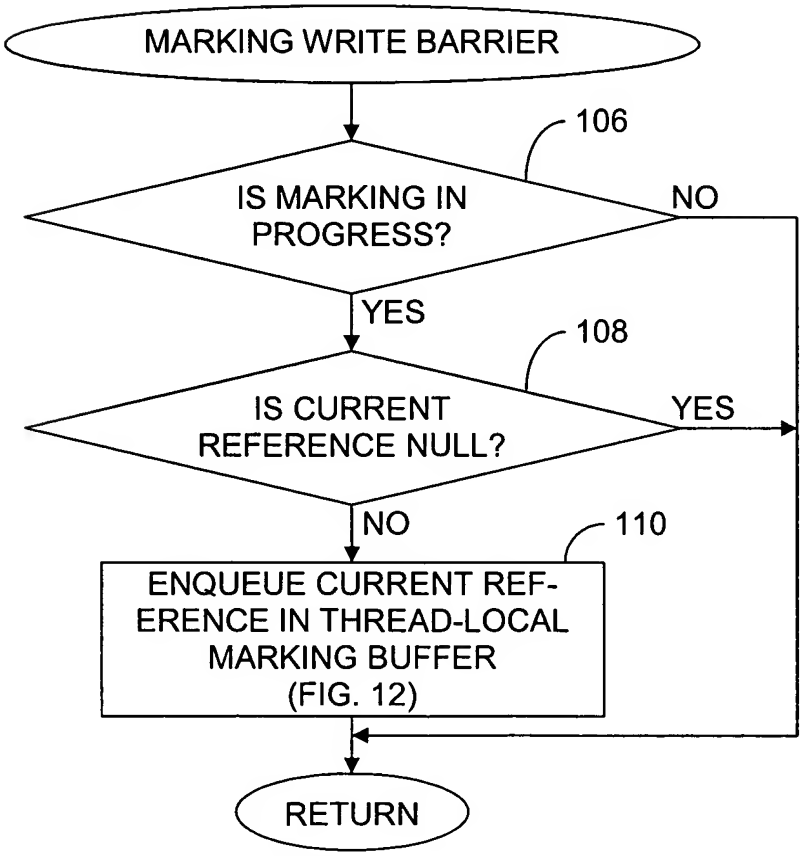
MARKING WRITE BARRIER
106
IS MARKING IN PROGRESS?
NO
YES
108
IS CURRENT REFERENCE NULL?
YES
NO
110
ENQUEUE CURRENT REFERENCE IN THREAD-LOCAL MARKING BUFFER (FIG. 12)
RETURN

FIG. 11

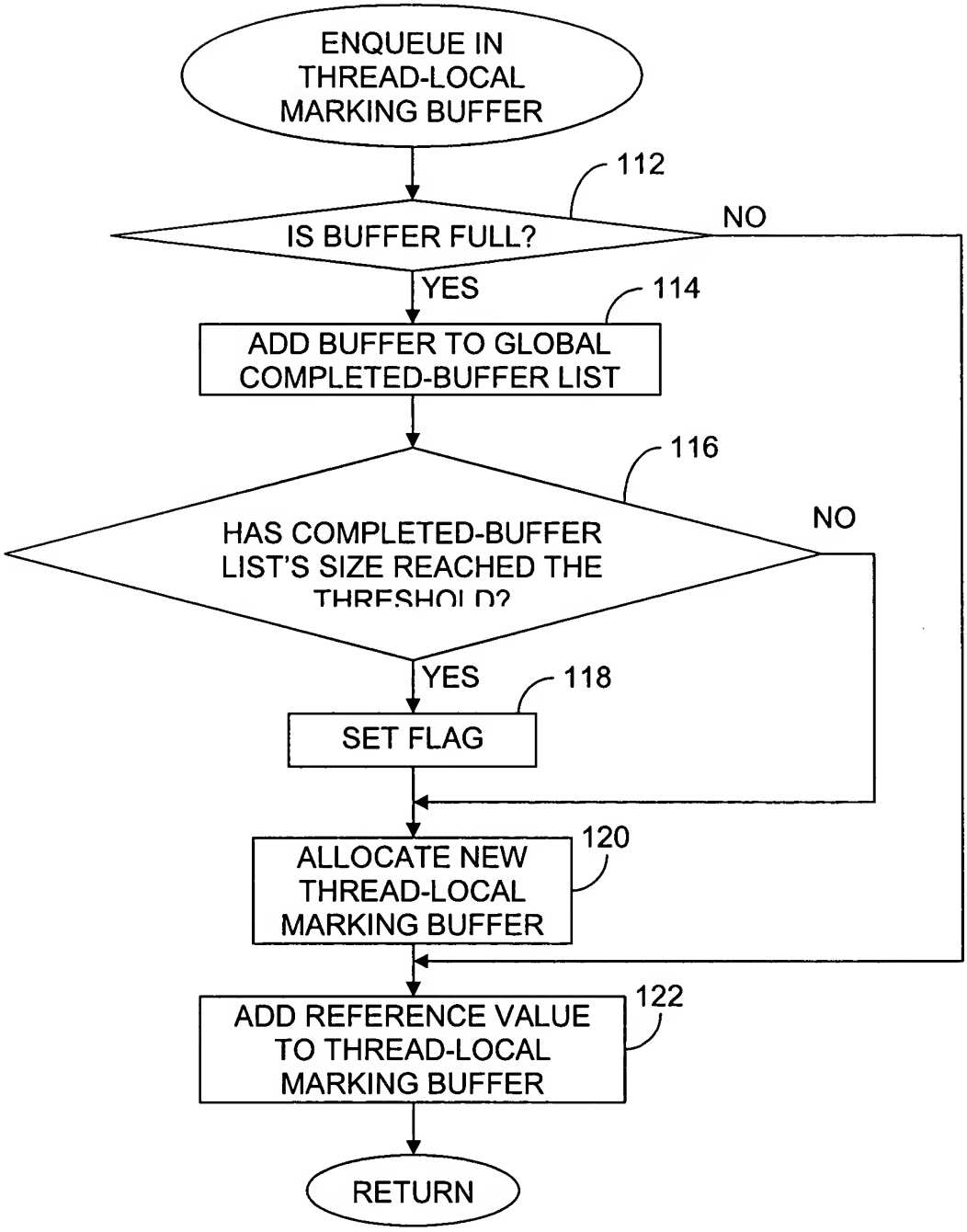
ENQUEUE IN THREAD-LOCAL MARKING BUFFER
112
IS BUFFER FULL?
NO
YES
114
ADD BUFFER TO GLOBAL COMPLETED-BUFFER LIST
116
HAS COMPLETED-BUFFER LIST'S SIZE REACHED THE THRESHOLD?
NO
YES
118
SET FLAG
120
ALLOCATE NEW THREAD-LOCAL MARKING BUFFER
122
ADD REFERENCE VALUE TO THREAD-LOCAL MARKING BUFFER
RETURN

FIG. 12

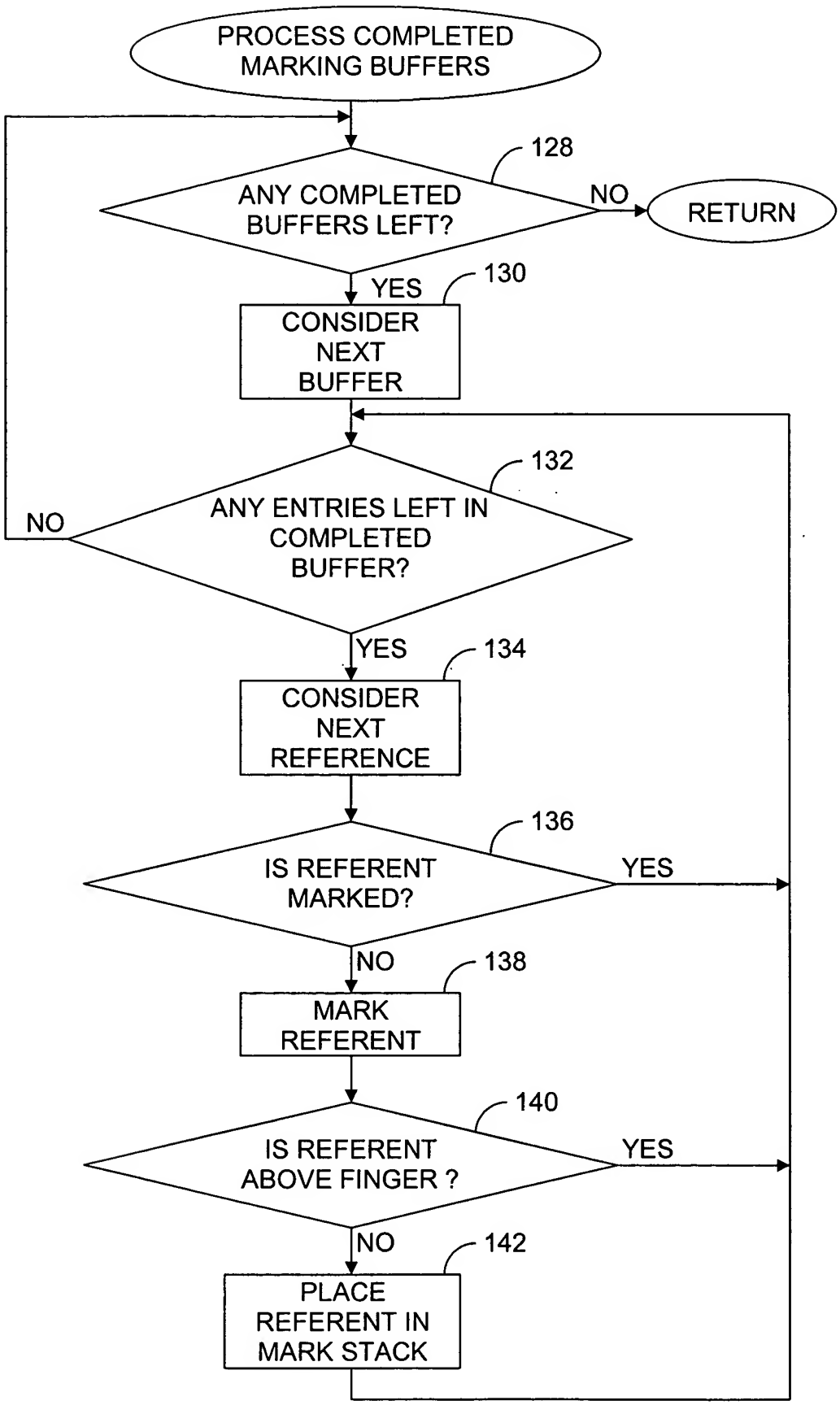
PROCESS COMPLETED MARKING BUFFERS
128
ANY COMPLETED BUFFERS LEFT?
NO
RETURN
YES
130
CONSIDER NEXT BUFFER
132
ANY ENTRIES LEFT IN COMPLETED BUFFER?
NO
YES
134
CONSIDER NEXT REFERENCE
136
IS REFERENT MARKED?
YES
NO
138
MARK REFERENT
140
IS REFERENT ABOVE FINGER ?
YES
NO
142
PLACE REFERENT IN MARK STACK

FIG. 13

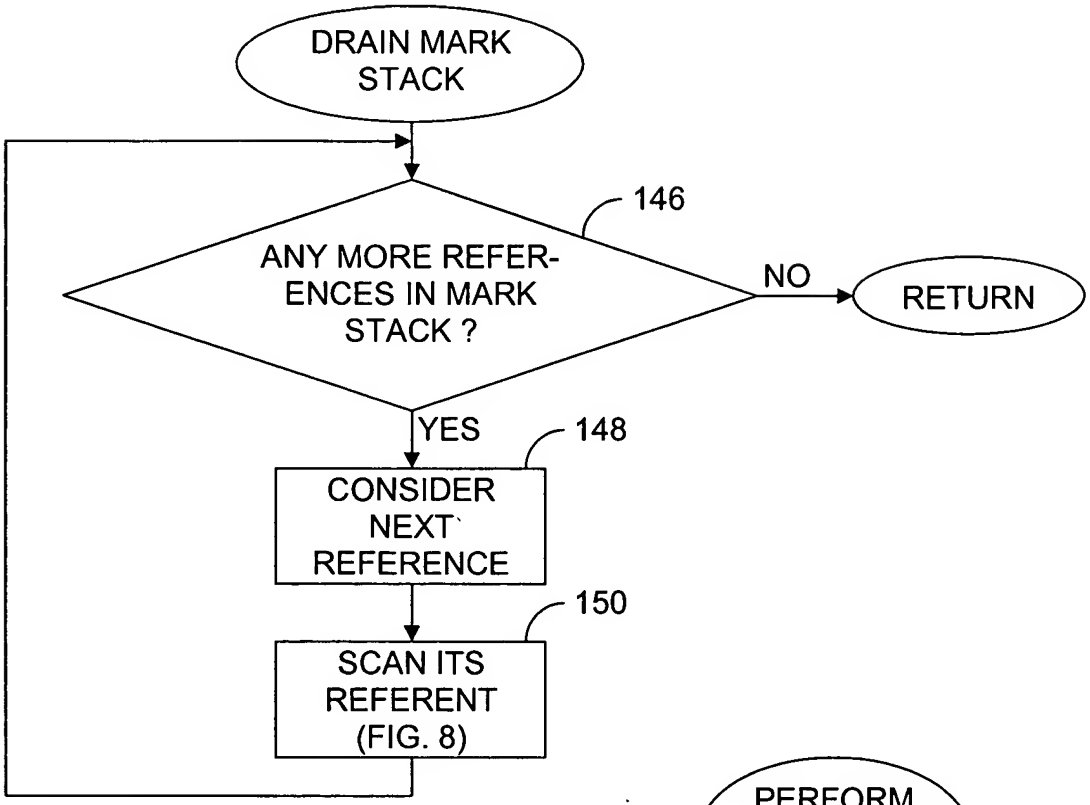
DRAIN MARK STACK
146
ANY MORE REFER-ENCES IN MARK STACK ?
NO
RETURN
YES
148
CONSIDER NEXT REFERENCE
150
SCAN ITS REFERENT (FIG. 8)

FIG. 14

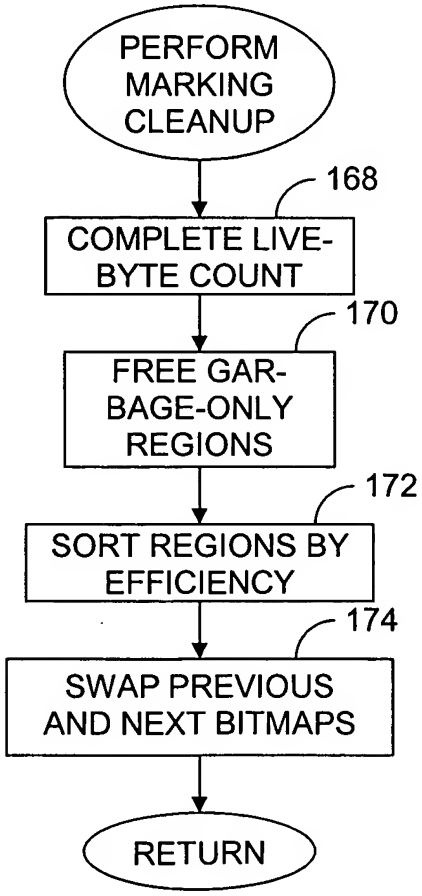
PERFORM MARKING CLEANUP
168
COMPLETE LIVE-BYTE COUNT
170
FREE GAR-BAGE-ONLY REGIONS
172
SORT REGIONS BY EFFICIENCY
174
SWAP PREVIOUS AND NEXT BITMAPS
RETURN

FIG. 15

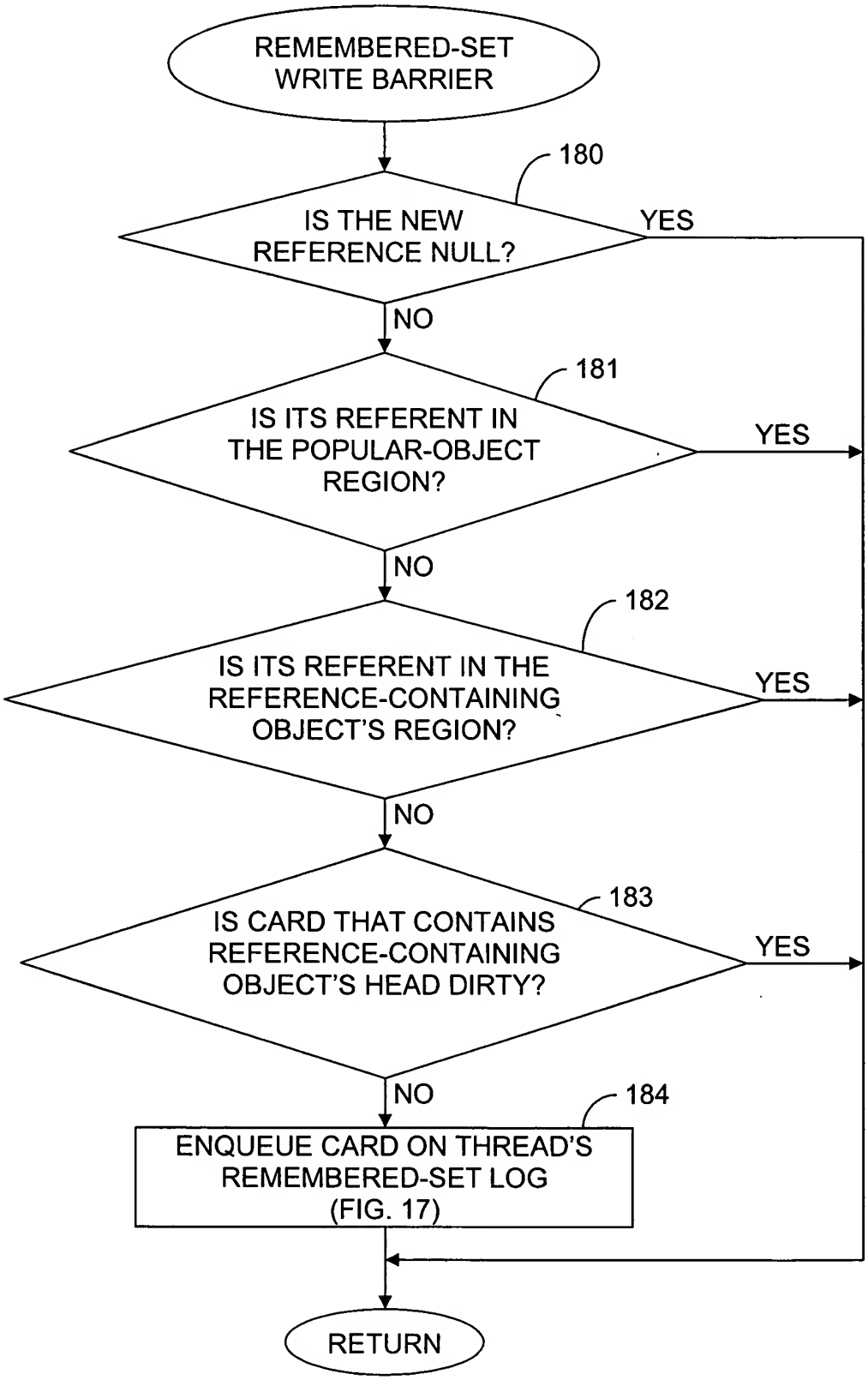
REMEMBERED-SET WRITE BARRIER
180
IS THE NEW REFERENCE NULL?
YES
NO
181
IS ITS REFERENT IN THE POPULAR-OBJECT REGION?
YES
NO
182
IS ITS REFERENT IN THE REFERENCE-CONTAINING OBJECT'S REGION?
YES
NO
183
IS CARD THAT CONTAINS REFERENCE-CONTAINING OBJECT'S HEAD DIRTY?
YES
NO
184
ENQUEUE CARD ON THREAD'S REMEMBERED-SET LOG (FIG. 17)
RETURN

FIG. 16

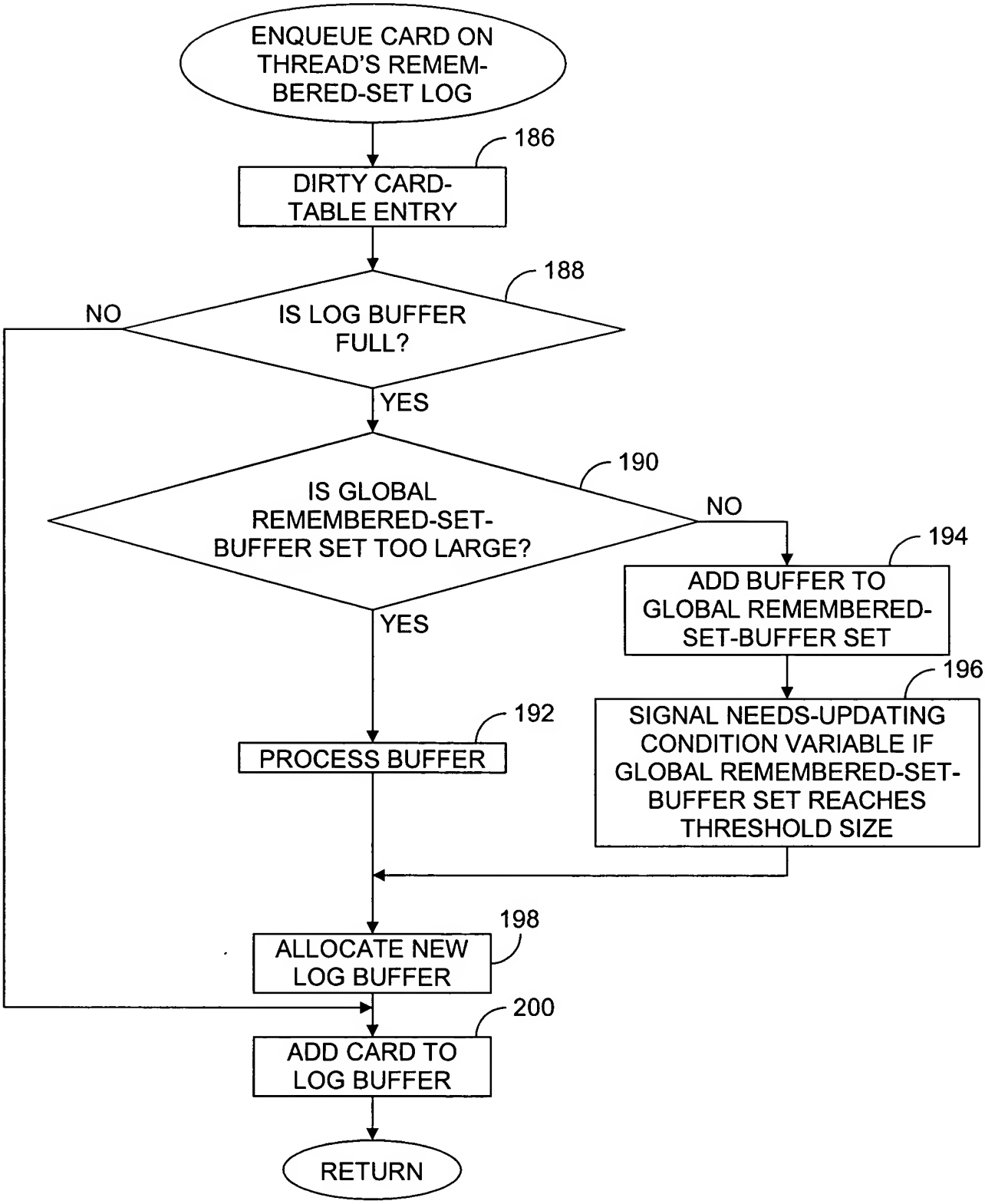
ENQUEUE CARD ON THREAD'S REMEMBERED-SET LOG
186
DIRTY CARD-TABLE ENTRY
188
IS LOG BUFFER FULL?
NO
YES
190
IS GLOBAL REMEMBERED-SET-BUFFER SET TOO LARGE?
NO
YES
194
ADD BUFFER TO GLOBAL REMEMBERED-SET-BUFFER SET
196
SIGNAL NEEDS-UPDATING CONDITION VARIABLE IF GLOBAL REMEMBERED-SET-BUFFER SET REACHES THRESHOLD SIZE
192
PROCESS BUFFER
198
ALLOCATE NEW LOG BUFFER
200
ADD CARD TO LOG BUFFER
RETURN

FIG. 17

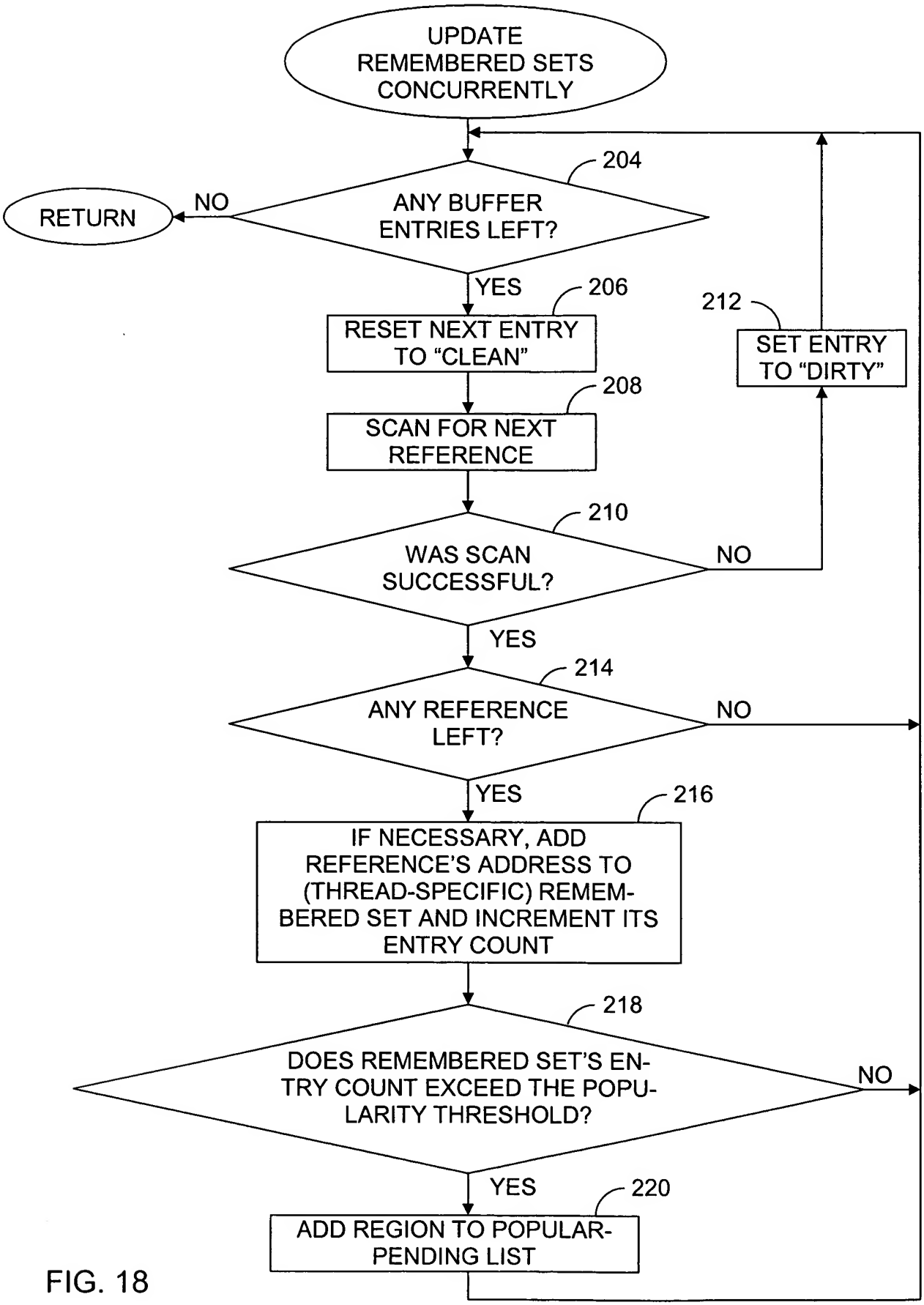
UPDATE REMEMBERED SETS CONCURRENTLY
204
ANY BUFFER ENTRIES LEFT?
NO
RETURN
YES
206
RESET NEXT ENTRY TO "CLEAN"
208
SCAN FOR NEXT REFERENCE
210
WAS SCAN SUCCESSFUL?
NO
212
SET ENTRY TO "DIRTY"
YES
214
ANY REFERENCE LEFT?
NO
YES
216
IF NECESSARY, ADD REFERENCE'S ADDRESS TO (THREAD-SPECIFIC) REMEMBERED SET AND INCREMENT ITS ENTRY COUNT
218
DOES REMEMBERED SET'S ENTRY COUNT EXCEED THE POPULARITY THRESHOLD?
NO
YES
220
ADD REGION TO POPULAR-PENDING LIST

FIG. 18

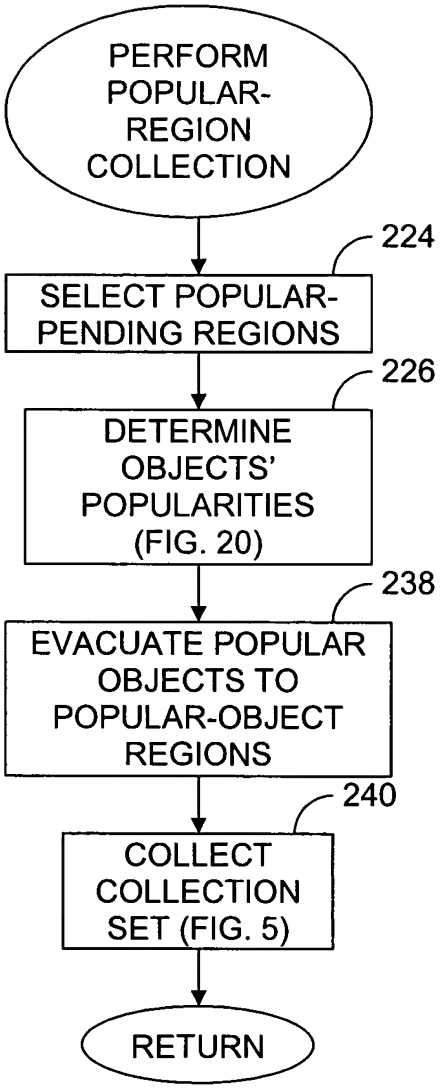
PERFORM POPULAR-REGION COLLECTION
224
SELECT POPULAR-PENDING REGIONS
226
DETERMINE OBJECTS' POPULARITIES (FIG. 20)
238
EVACUATE POPULAR OBJECTS TO POPULAR-OBJECT REGIONS
240
COLLECT COLLECTION SET (FIG. 5)
RETURN

FIG. 19

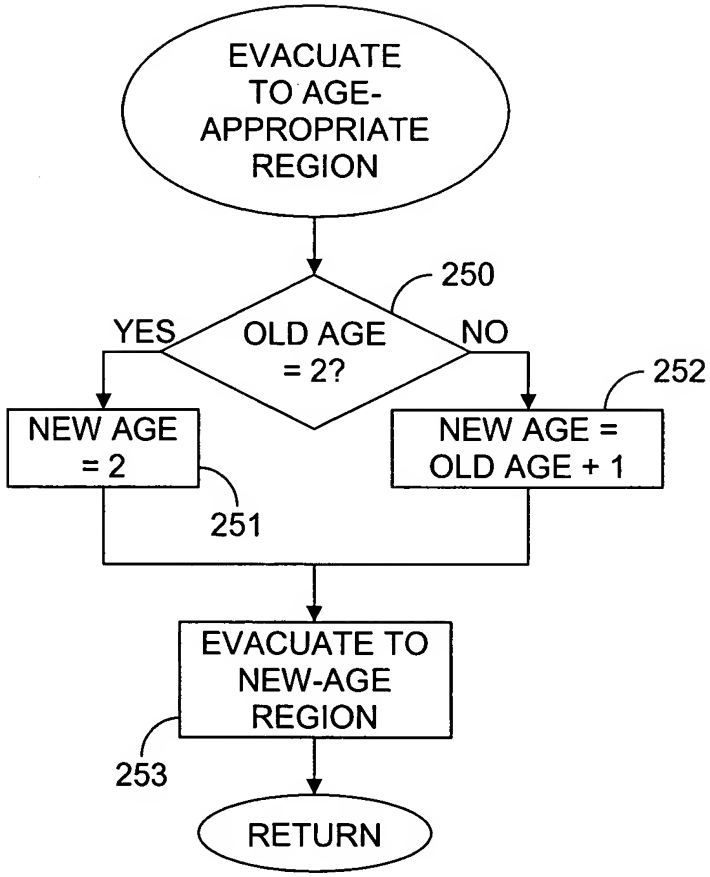
EVACUATE TO AGE-APPROPRIATE REGION
250
OLD AGE = 2?
YES
NO
NEW AGE = 2
251
NEW AGE = OLD AGE + 1
252
EVACUATE TO NEW-AGE REGION
253
RETURN

FIG. 22

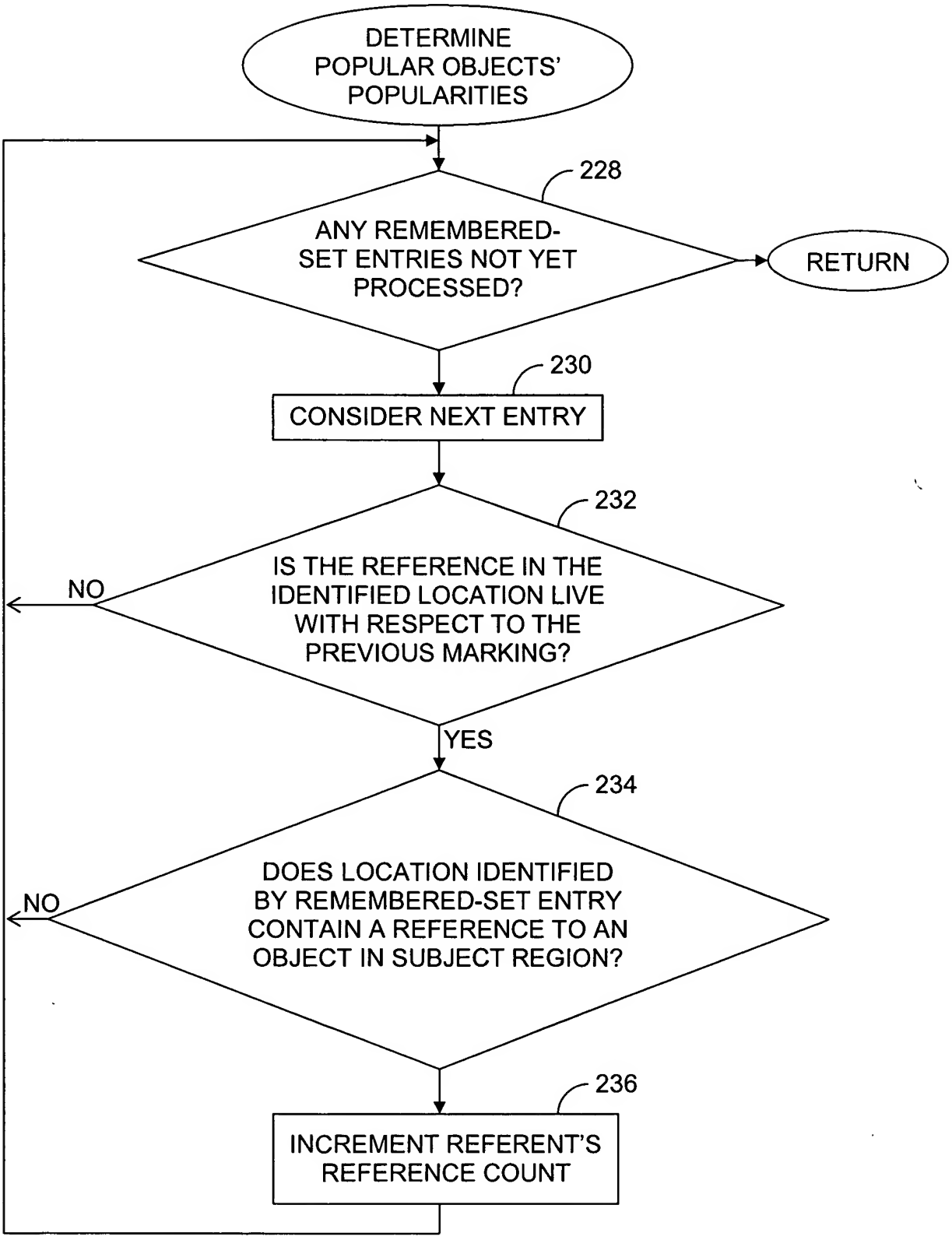
DETERMINE POPULAR OBJECTS' POPULARITIES
228
ANY REMEMBERED-SET ENTRIES NOT YET PROCESSED?
RETURN
230
CONSIDER NEXT ENTRY
232
IS THE REFERENCE IN THE IDENTIFIED LOCATION LIVE WITH RESPECT TO THE PREVIOUS MARKING?
NO
YES
234
DOES LOCATION IDENTIFIED BY REMEMBERED-SET ENTRY CONTAIN A REFERENCE TO AN OBJECT IN SUBJECT REGION?
NO
236
INCREMENT REFERENT'S REFERENCE COUNT

FIG. 20

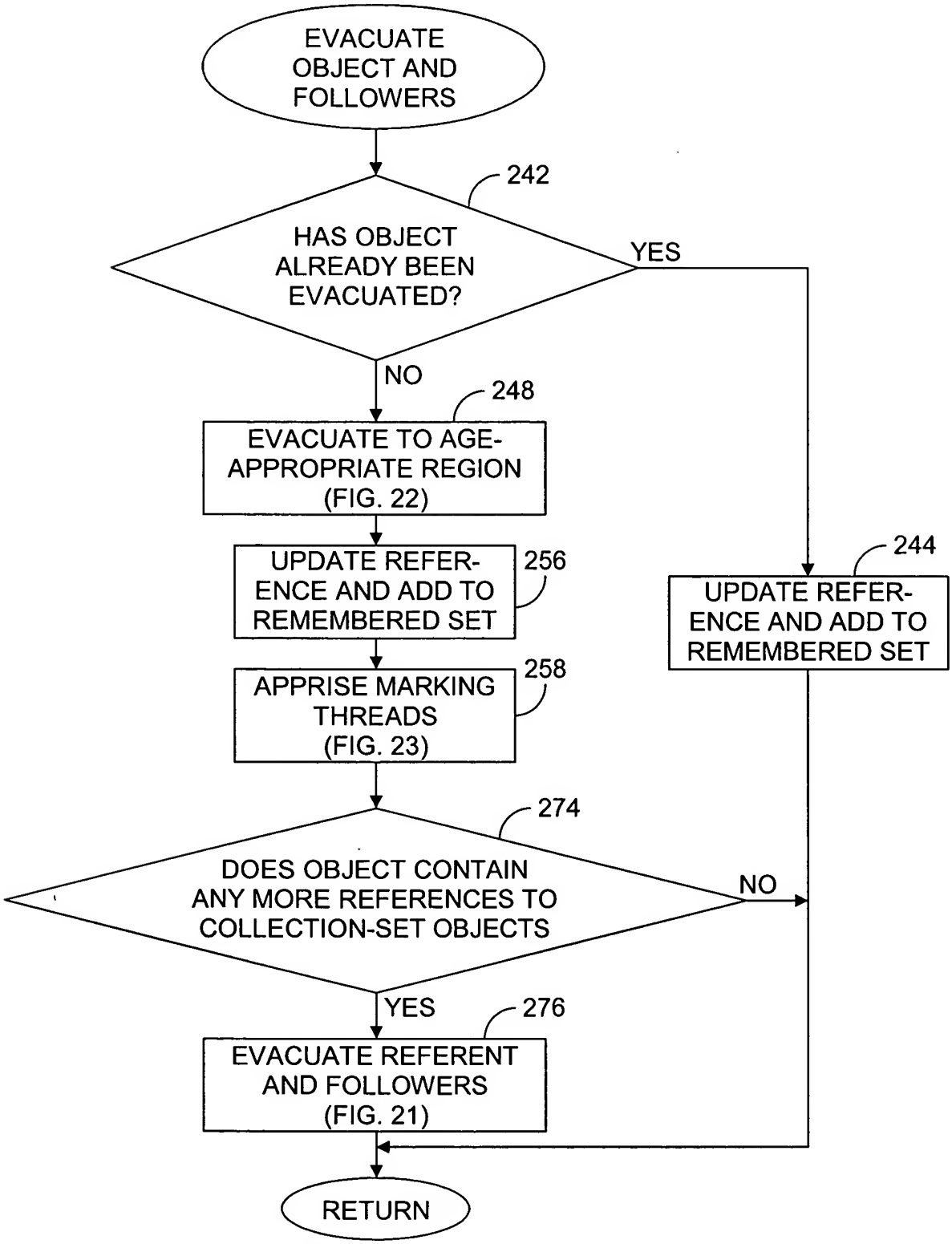
EVACUATE OBJECT AND FOLLOWERS
242
HAS OBJECT ALREADY BEEN EVACUATED?
YES
NO
248
EVACUATE TO AGE-APPROPRIATE REGION (FIG. 22)
UPDATE REFER-ENCE AND ADD TO REMEMBERED SET
256
APPRISE MARKING THREADS (FIG. 23)
258
244
UPDATE REFER-ENCE AND ADD TO REMEMBERED SET
274
DOES OBJECT CONTAIN ANY MORE REFERENCES TO COLLECTION-SET OBJECTS
NO
YES
276
EVACUATE REFERENT AND FOLLOWERS (FIG. 21)
RETURN

FIG. 21

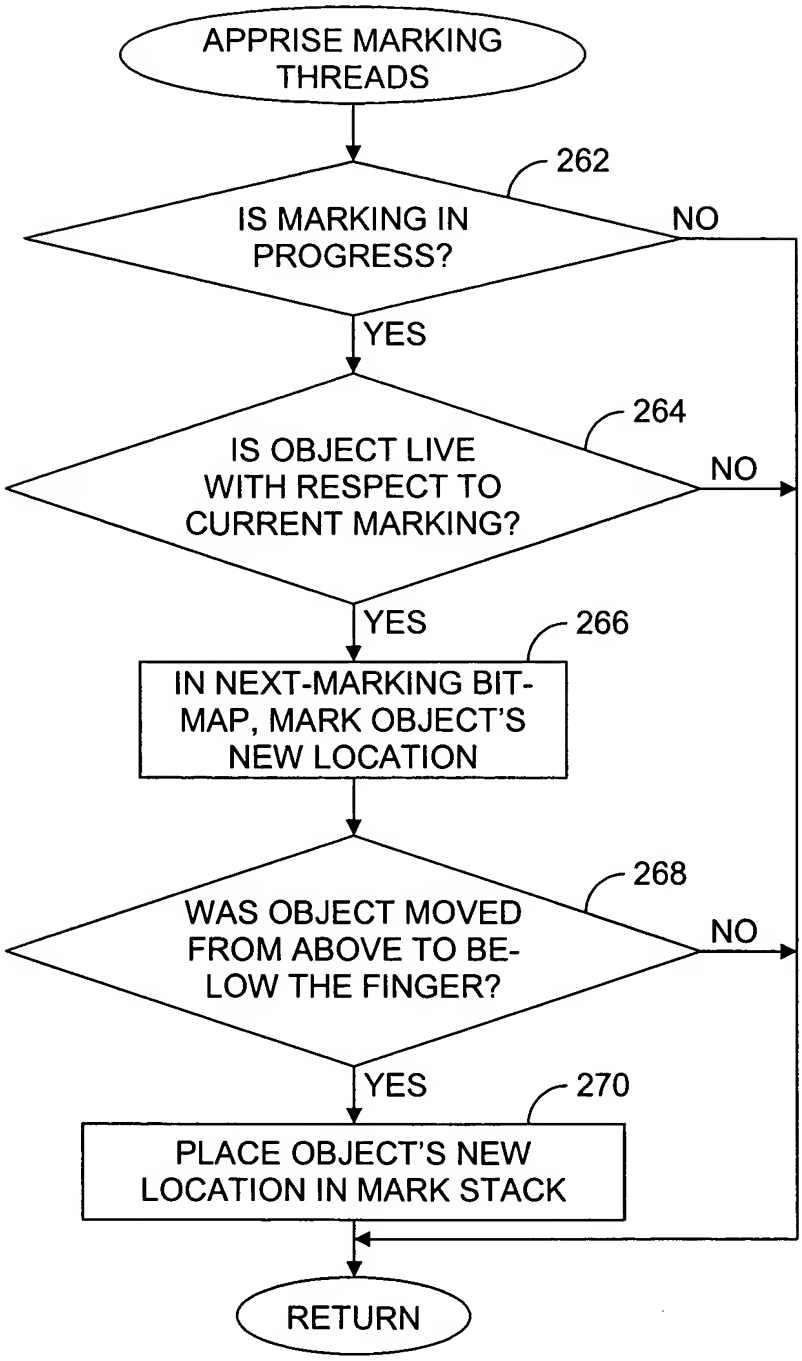
APPRISE MARKING THREADS
262
IS MARKING IN PROGRESS?
NO
YES
264
IS OBJECT LIVE WITH RESPECT TO CURRENT MARKING?
NO
YES
266
IN NEXT-MARKING BIT-MAP, MARK OBJECT'S NEW LOCATION
268
WAS OBJECT MOVED FROM ABOVE TO BE-LOW THE FINGER?
NO
YES
270
PLACE OBJECT'S NEW LOCATION IN MARK STACK
RETURN

FIG. 23

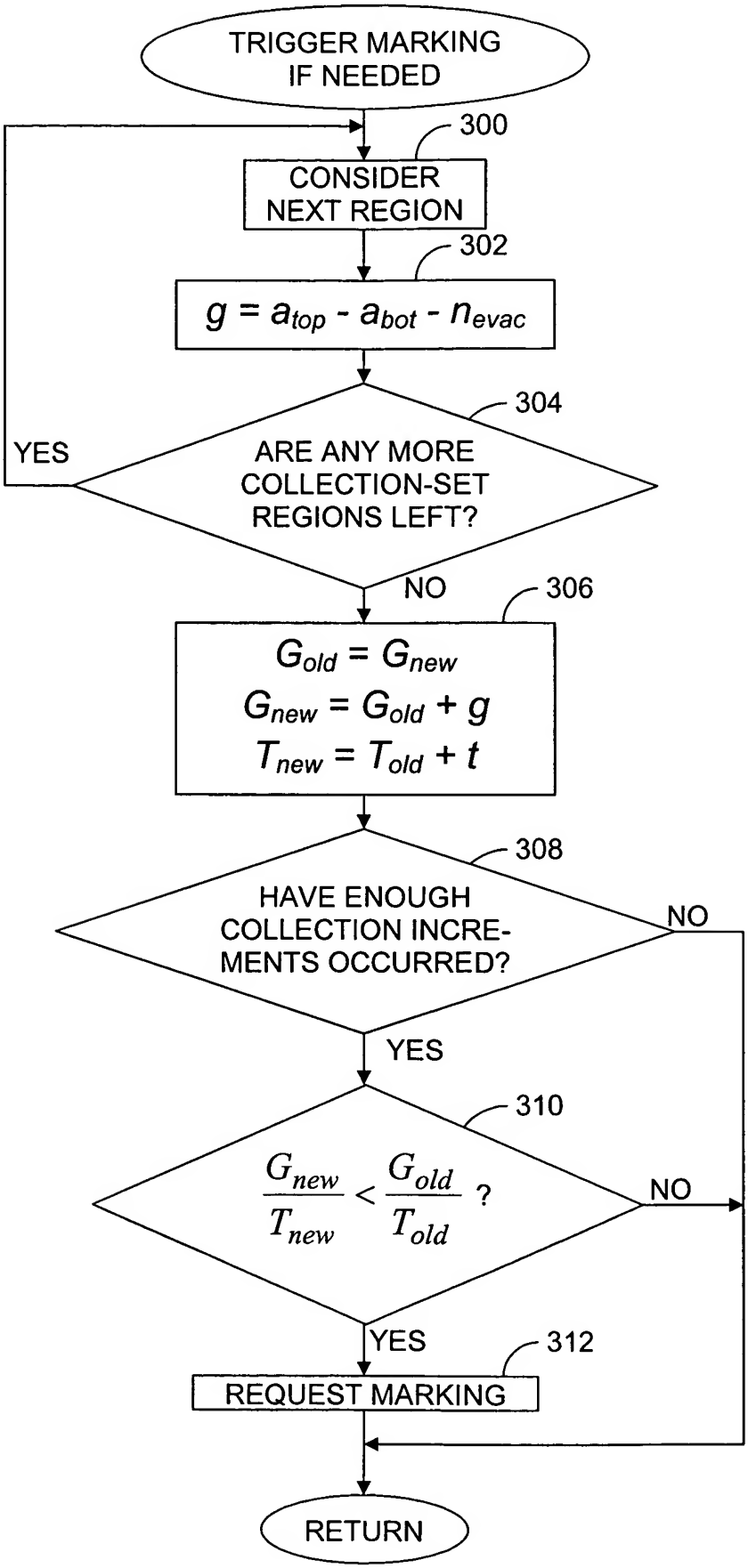
TRIGGER MARKING IF NEEDED
300
CONSIDER NEXT REGION
302
$g = a_{top} - a_{bot} - n_{evac}$
304
YES
ARE ANY MORE COLLECTION-SET REGIONS LEFT?
NO
306
$G_{old} = G_{new}$
$G_{new} = G_{old} + g$
$T_{new} = T_{old} + t$
308
HAVE ENOUGH COLLECTION INCRE-MENTS OCCURRED?
NO
YES
310
$\frac{G_{new}}{T_{new}} < \frac{G_{old}}{T_{old}}$?
NO
YES
312
REQUEST MARKING
RETURN

FIG. 24